CF3 Summary
Non-WIMP Dark Matter

Alex Kusenko
Leslie Rosenberg

Cosmic Frontier Meeting, SLAC 06-08 March 2013

Wide-Ranging, Lively Discussion

Wednesday:

Pierre Sikivie “An Argument that the Dark-Matter is Axions”
Maurizio Gionnotti “Astrophysical Constraints on Axion-Photon Coupling”
Kyu Junk Bae “Cosmology of SUSY Axion Models”
Gray Rybka “ADMX Current Status”
Karl van Bibber “ADMX-HF”
Gianpaolo Carosi “Microwave Cavity R&D for Axion Cavity Searches”
Michael Pivovarov “IAXO: International Axion Observatory”
Ariel Zhitnitsky “Dark Matter & Baryogenesis as Two Sides of the Same Coin”
Kyle Lawson “Ground-Based Quark Nugget Search”
Javier Redondo “IAXO and the Science Case”
Agnieszka Ciepiak “Contraining Primordial Black Hole Dark Matter Using Microlensing”
Jeremy Mardon “Direct Detection Beyond the WINP Paradigm”

Wide-Ranging Discussion (continued)

Thursday:

Takeo Moroi “Non-WIMP Dark Matter in SUSY Models
Yasunori Nomura “A Theoretical Perspective on Dark Matter”
Clifford Cheung “Non-WIMP Zoology”
Jiji “Double-Disk Dark Matter” (joint CF6)
Kris Sigurdson “Dark Matter Antibaryons and Induced Nucleon Decay” (joint CF6)
George Fuller “Dark Matter and Supernovae”
Kevork Abazajian “The Status of Sterile Neutrino Dark Matter”
Oleg Ruchaiskiy “Sterile Neutrinos as Dark Matter”
David Cline “The Search for Low-Mass WIMPs”
Leonidas Moustakis “Shedding Light”
Jenniver Seigel-Gaskins “Constraints on Sterile Neutrinos DM From Fermi …”

Friday (with CF4):

Louis Strigari “Is there observed tension between small-scale structure and CDM?”
Hector de Vega “Fermionic WDM Reproduces Galaxy Observations because of Q.M.”
Dodelson “Current and Future Cosmological Constraints on Neutrinos”

Some themes in non-WIMP dark matter sessions

Discovery involves guessing the answer.
Guesses include a very broad range of dark-matter candidates.

The guesses incorporate compelling theoretical Ideas and astrophysical hints.

The guesses also account for available technology. There's nothing wrong with searching under the lamppost If you don't know where you lost your keys.

There's a scientific ideology at play in the sessions:
1. Balanced approach: Input taken from everybody. The body didn't think any one path is necessarily the answer.
2. Comprehensive: Broad set of theory and observational strategies.
3. "Holistic": Take what nature's telling us. Take various constraints *in toto*.

CF3 Approach in Practice

Two pre-meetings in March for community input.
Setting up discussion CF3 group; circulate written materials.
Welcome people sending materials, including ad hoc notes for workshop consideration, white papers, or reviews written for other occasions.

We don't necessarily want verbatim text, but want documents that can be digested for further planning and studies.

There's a repository for user-friendly access to CF3 materials.
With permission, will have public access on Twiki Snowmass site.
Non-public contributions also welcome.

Will follow up with communications to participants and broader Community Snowmass.

Recurring scientific themes in CF3

Axionic dark matter structure formation: Is this a unique signature, it this observable (e.g., via strong-lensing halo structure)?

SUSY: Friendly with WIMPs, but not married to WIMPs. Other candidates include gravitinos, axinos, Q-balls, etc.

Sterile neutrinos. Many discussions on searches and phenomenology.

Asymmetric dark matter.

Reconsider quark-nuggets and black holes. Review observational constraints. Consider WIMP-like particles with pure electron couplings.

Axion and ALP searches: Now sensitive and moving into the realm of "definitive searches"

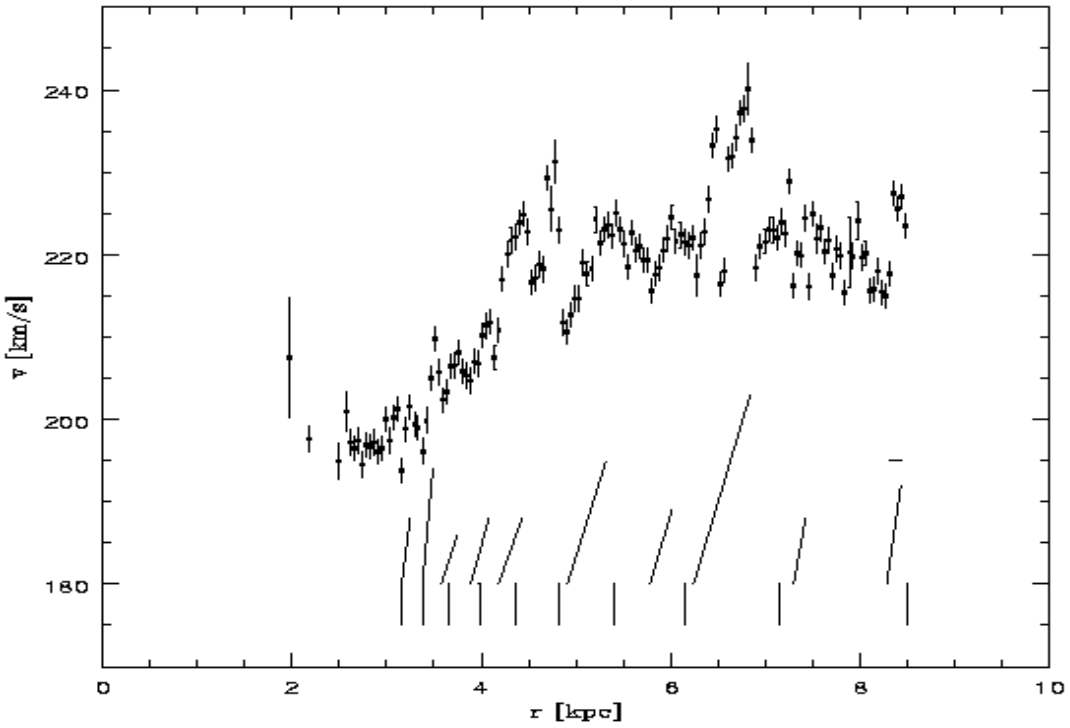
Astrophysics: Improve observations and theory. How to turn hints into detections.

A closer look at warm-dark matter and self-interacting dark matter.

Etc., etc., etc.

Sikivie: Does Structure Favor Axionic Dark Matter

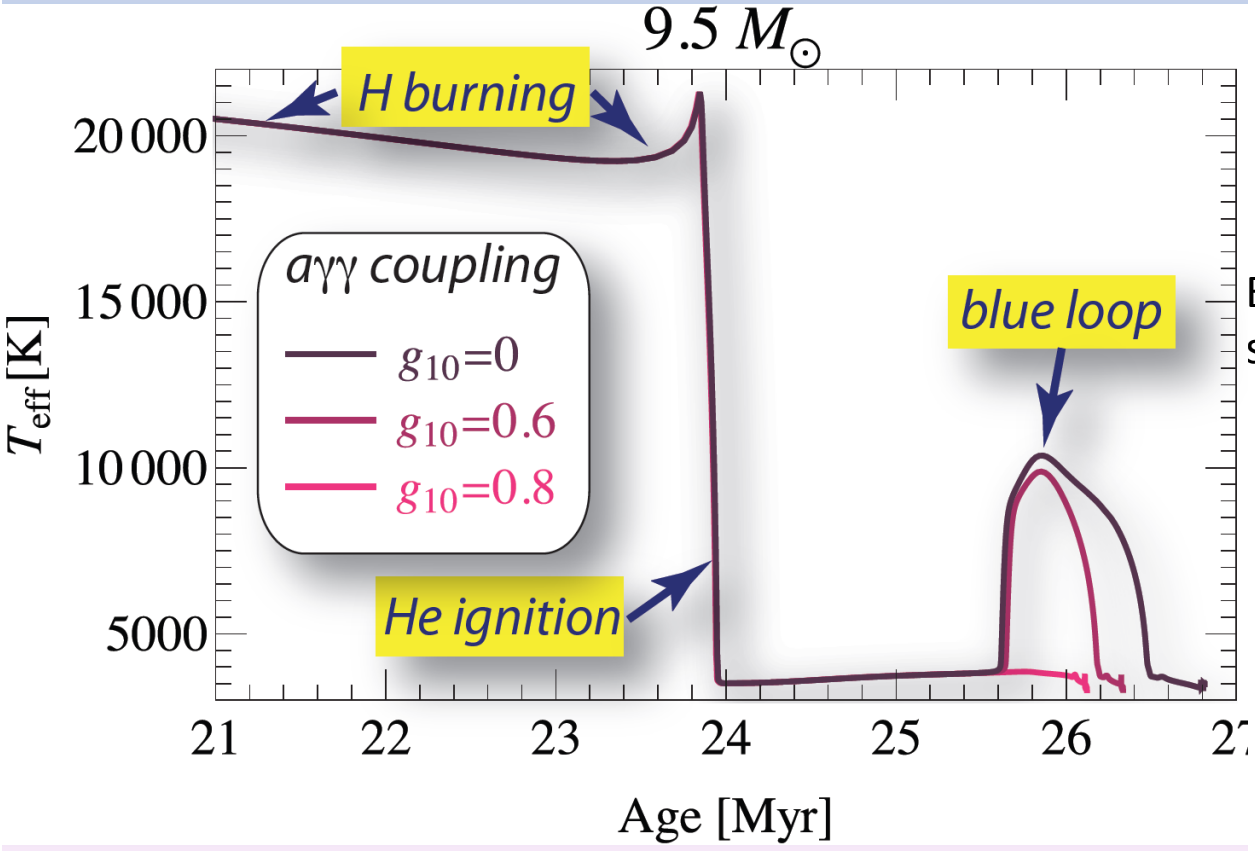
Inner Galactic rotation curve



Take Bose nature of axion dark matter into account. Is resulting structure a better match to structure? How about ^{7}Li?

from Massachusetts-Stony Brook North Galactic Pane CO Survey (Clemens, 1985)

Giannotti: Axions and the Evolution of Blue and Red Sequence Stars



Evolution of off-main sequence stars is sensitive to axion cooling

Kyu Jung Bae: SUSY plus Axions

Decay of Saxion:

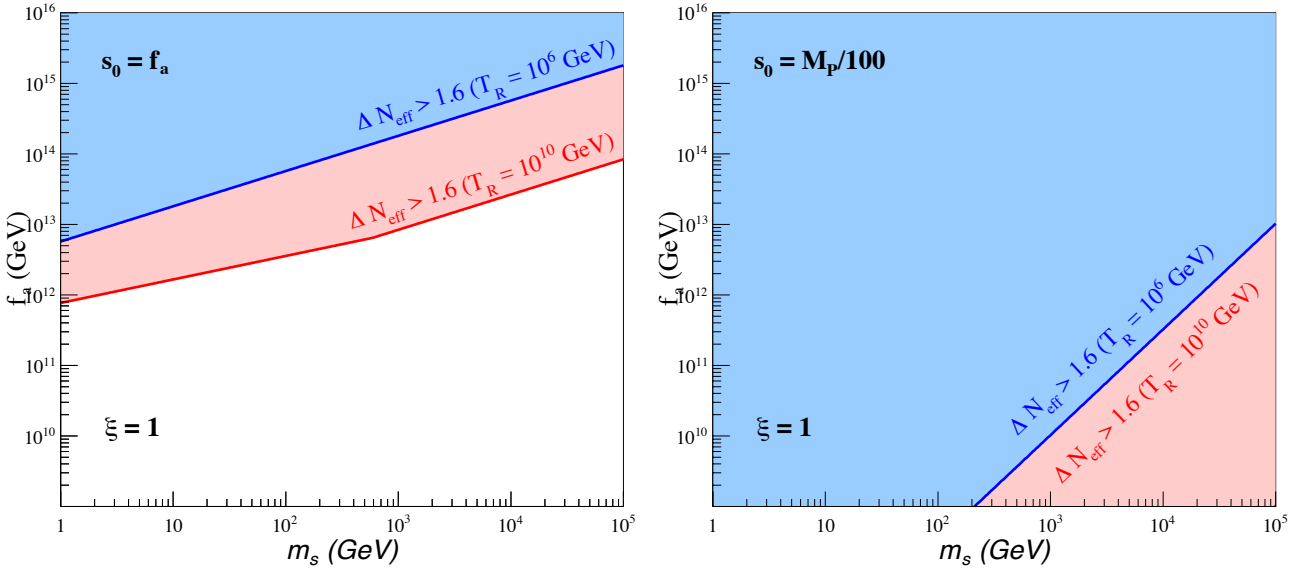
If the dominant mode is $s \to aa$

Ichikawa, Kawasaki, Nakayama, Senami, Takahashi; Moroi, Takimoto; Choi, Choi, Shin; KJB, Baer, Lessa; Jeong, Takahashi; Graf, Steffen

$\Rightarrow$ provides the dark radiation, constrained by CMB data.

$$\Delta N_\nu \lesssim 1.6$$

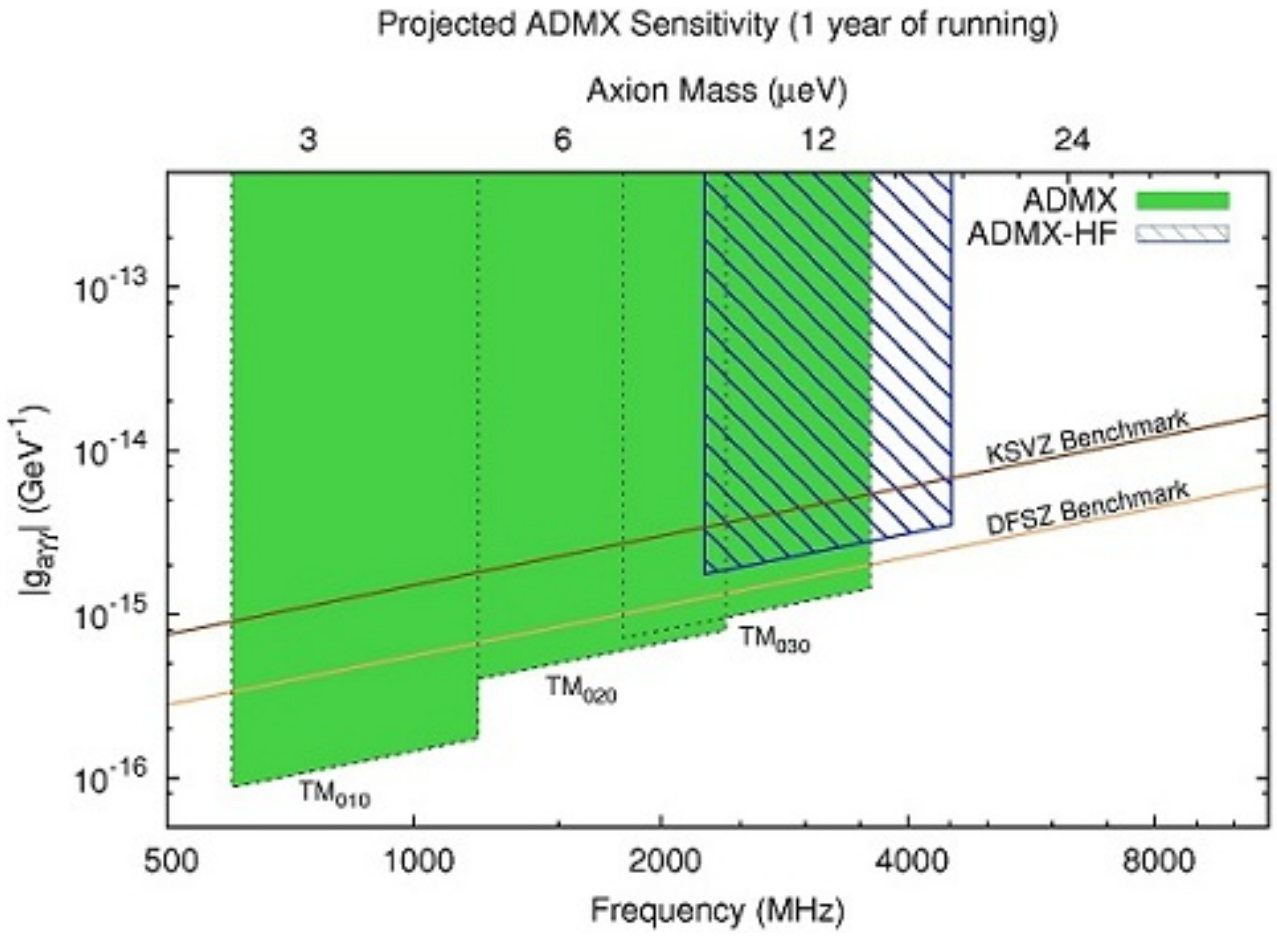
The axion and its superpartners are a surprisingly good pairing: dark-matter and dark-radiation

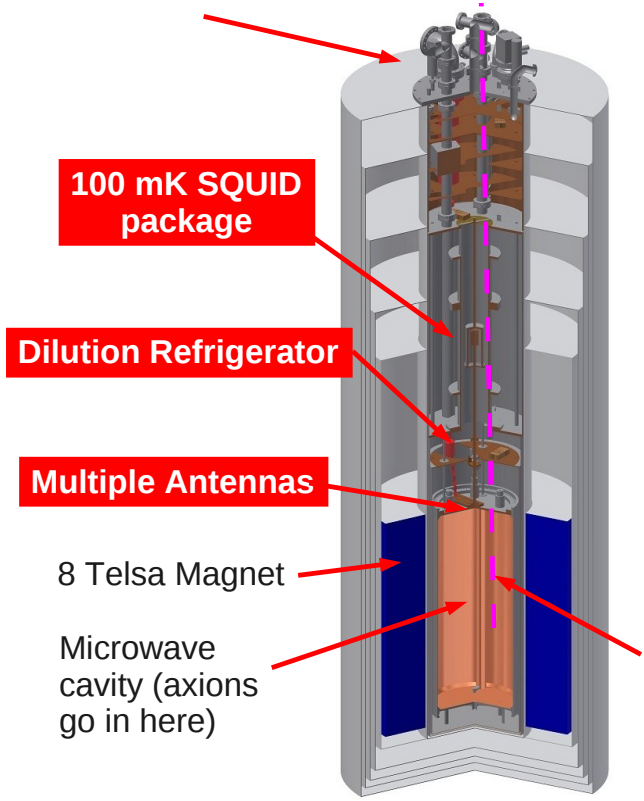


KJB, Baer, Lessa

Similar to axion CDM, $f_a \lesssim 10^{12}$ GeV $- 10^{13}$ GeV

Gray Rybka: ADMX RF-Cavity Axion Search





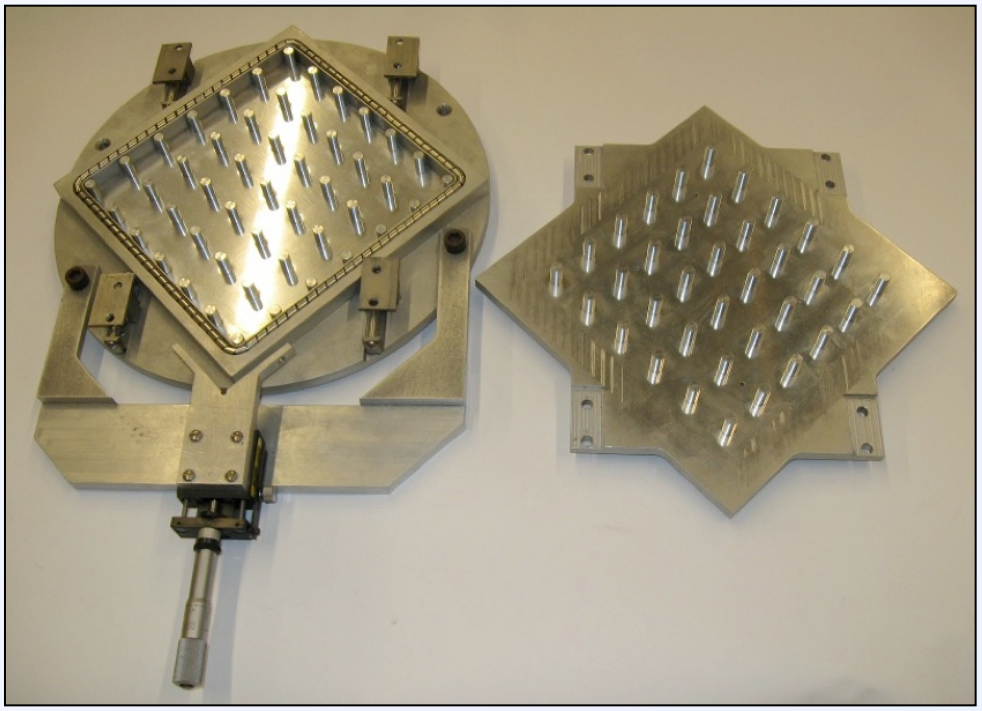
Able to detect the QCD axion or reject the hypothesis at high confidence.

van Bibber: RF-Cavity R&D Platform

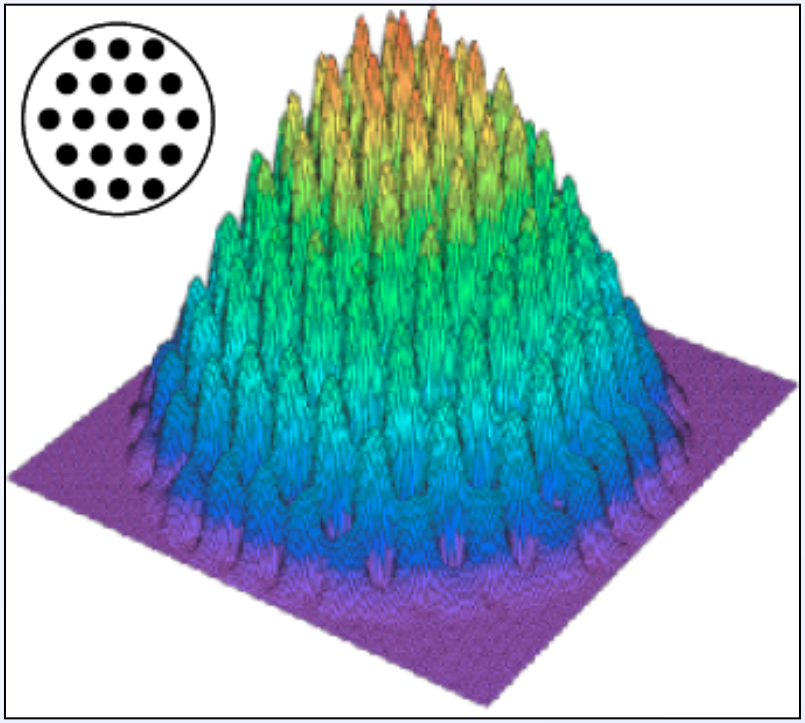
ADMX-HF: Hoping to advance high-Q superconducting materials in high magnetic fields.

Carosi: RF-Cavity R&D

Cavities for RF-cavity axion searches: High Q, tunable, good “form factor”.

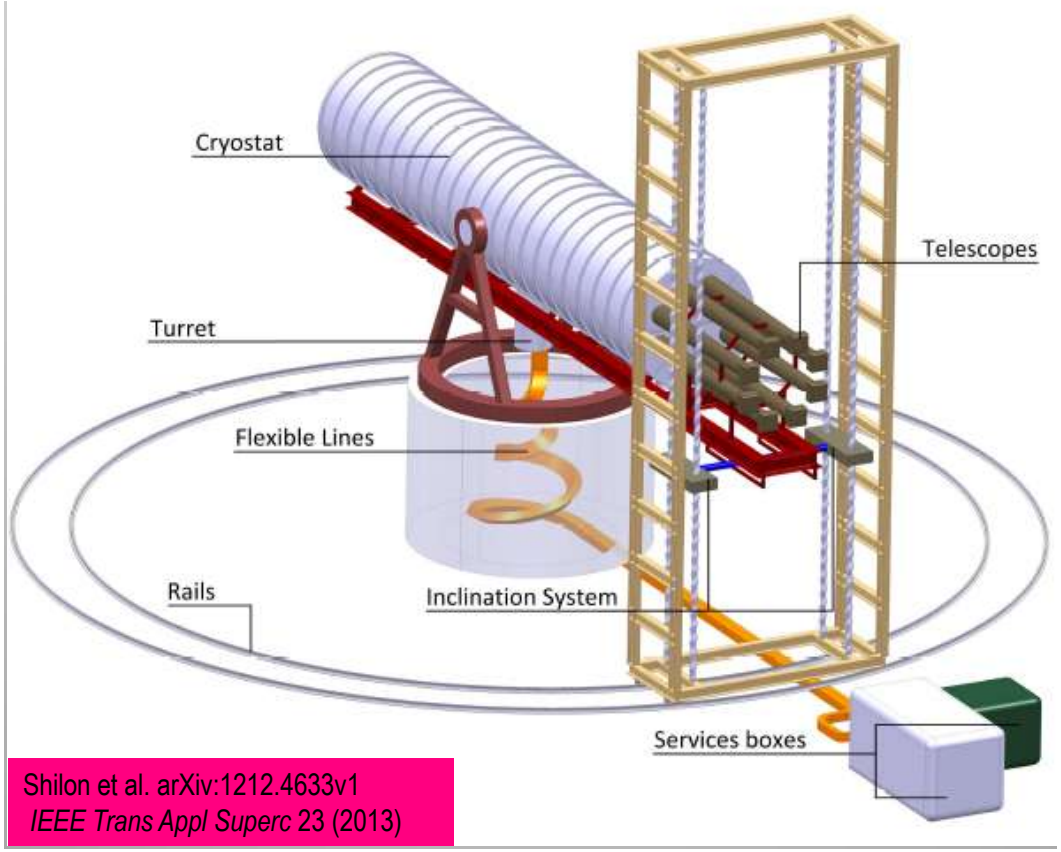


Prototype multipost cavity



***C. Hagmann simulation**

Pivovarov: IAXO



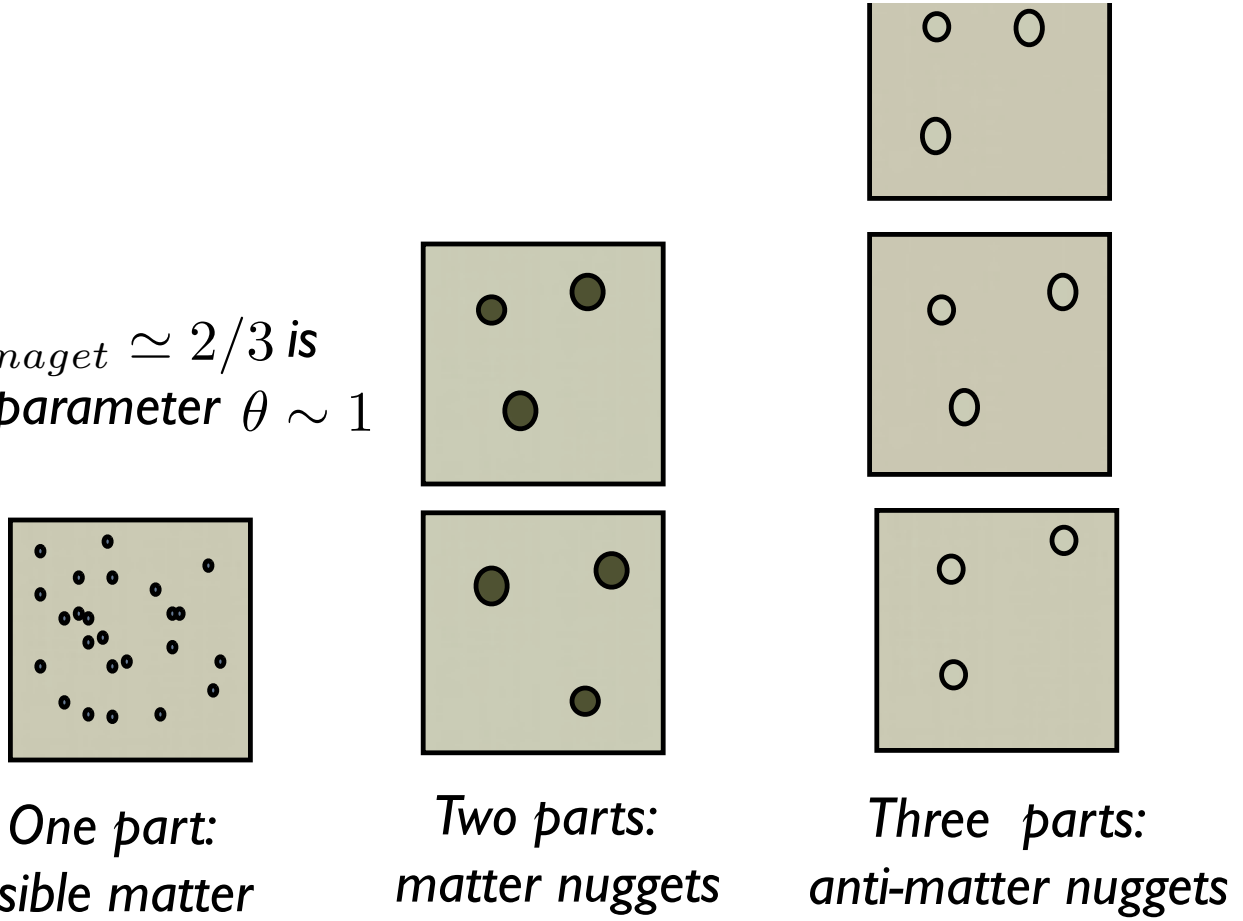
Shilon et al. arXiv:1212.4633v1
IEEE Trans Appl Superc 23 (2013)

International Axion Observatory:4th Generation Helioscope. Powerfully explores region of astrophysical hints of axions plus ...

Zhitnitsky: Axion, Dark Matter and Baryogenesis

Matter-Antimatter asymmetry is due to baryon number locked into quark matter …

The ratio $B_{nugget}/\bar{B}_{antinaget} \simeq 2/3$ *is determined by CP violating parameter* $\theta \sim 1$



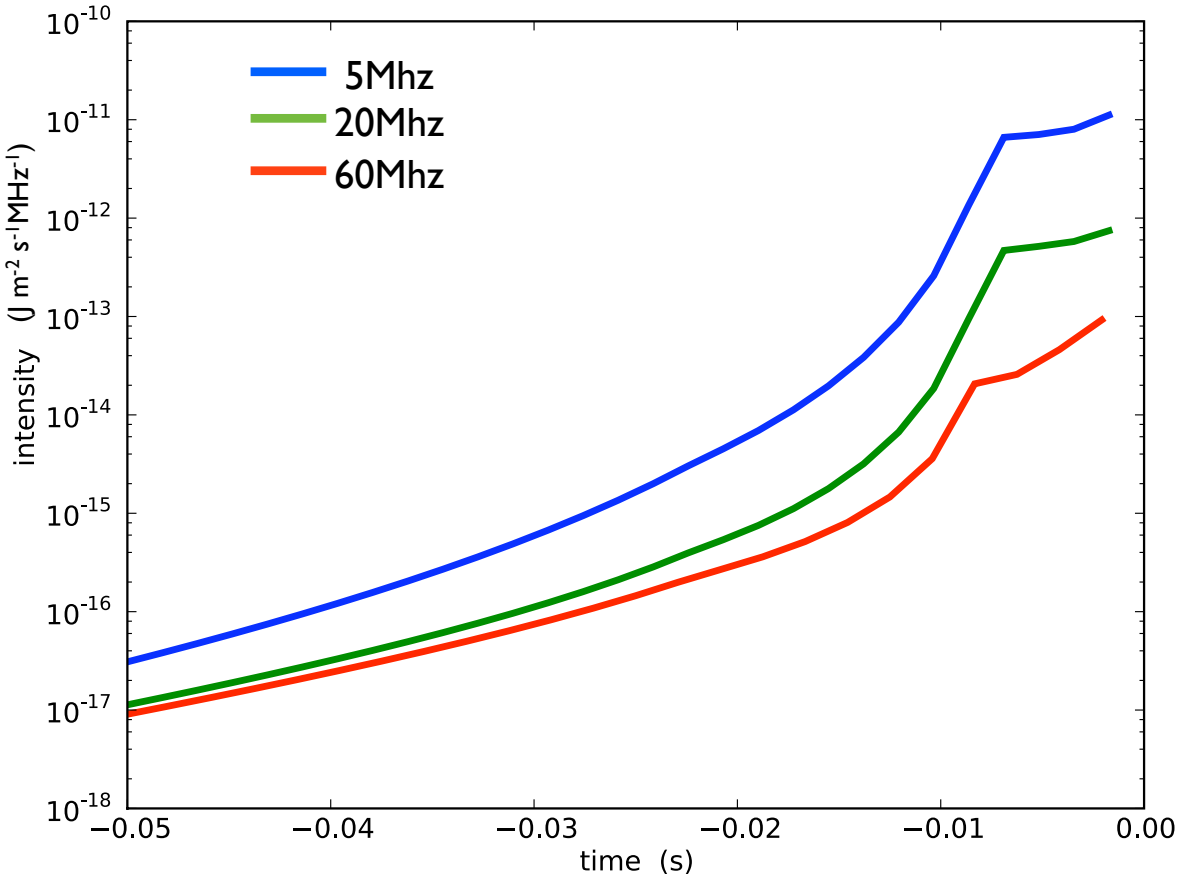
One part: visible matter

Two parts: matter nuggets

Three parts: anti-matter nuggets

Lawson: Detecting Quark Nuggets

The nugget hitting ice makes a radio signal …

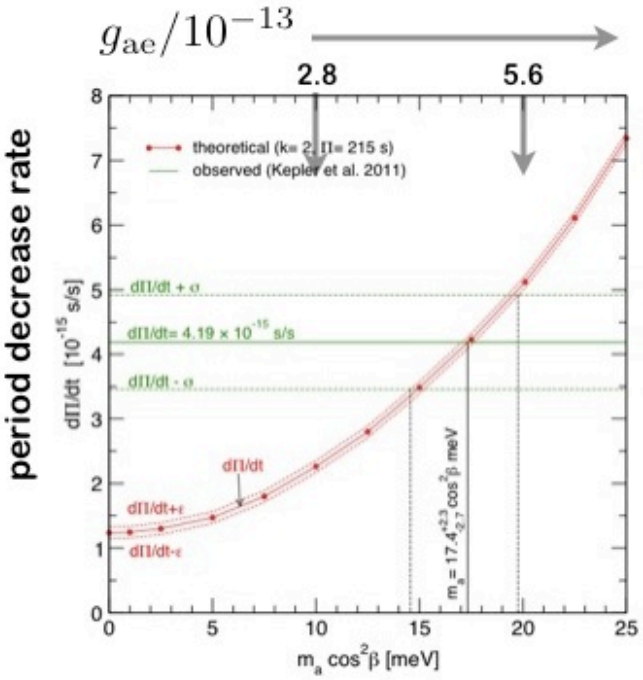


Redondo: Physics and IAXO

One of the IAXO science missions is exploring hints of ALPS …

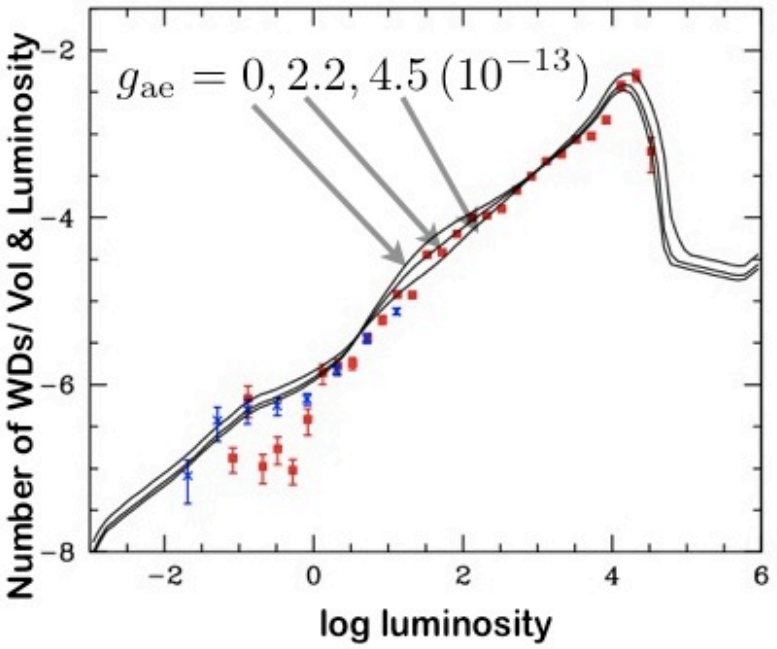
Period decrease of G117–B15A

Corsico et al. arXiv:1205.6180



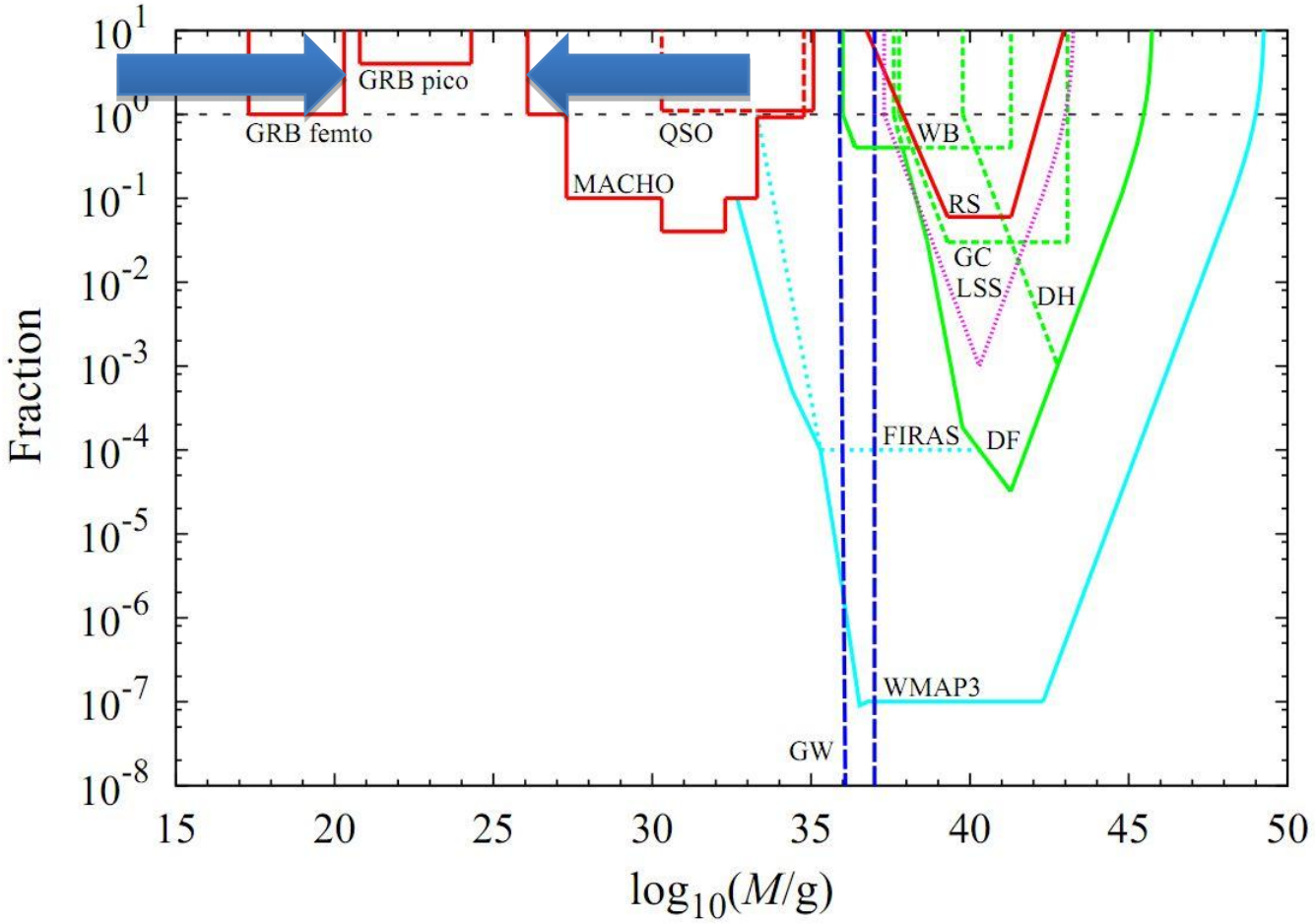
WD luminosity function

Isern et al. arXiv:1204.3565



Ciepiak: Kepler Mission and BH Lensing

Closing the PBH window



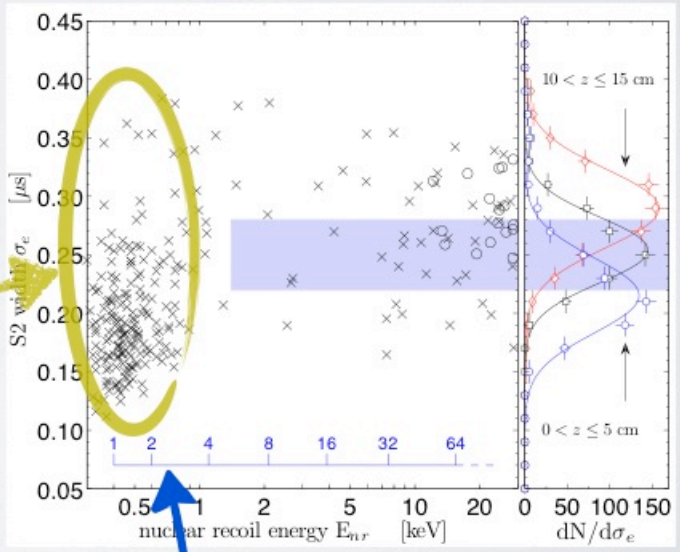
Mardon: Low mass WIMP-like particles coupling to electrons

Low mass WIMPs and electron recoils

XENON10:

- **Incredible sensitivity: could measure single electrons**
- **Hardware trigger only recorded single electrons during a 15 kg-day exp. in 2006**
- **Published in 2011**

"A search for light dark matter in XENON10 data"
1104.3088



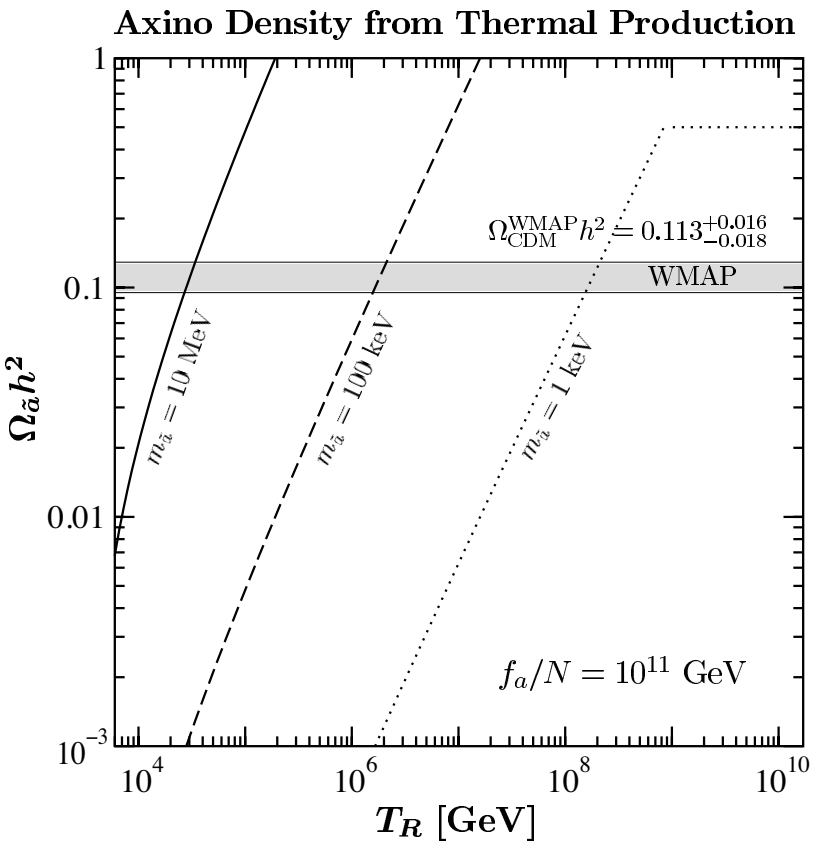
single/few-electron events

number of ionized electrons

Moroi: SUSY supplies a host of dark-matter candidates

Density parameter of axino (for $f_a = 10^{11}$ GeV)

Axino dark matter …

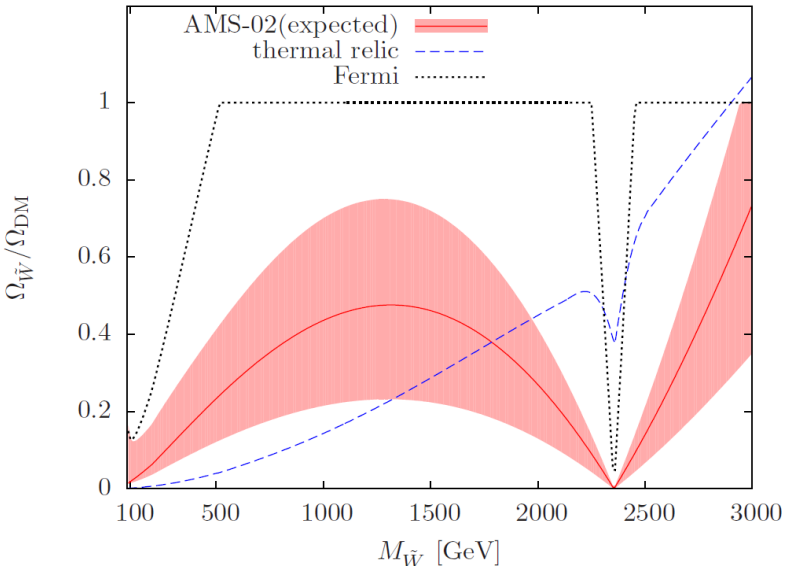


Nomura: Reconsider naturalness

Host of DM-like relics …

Cosmic / astrophysical signals

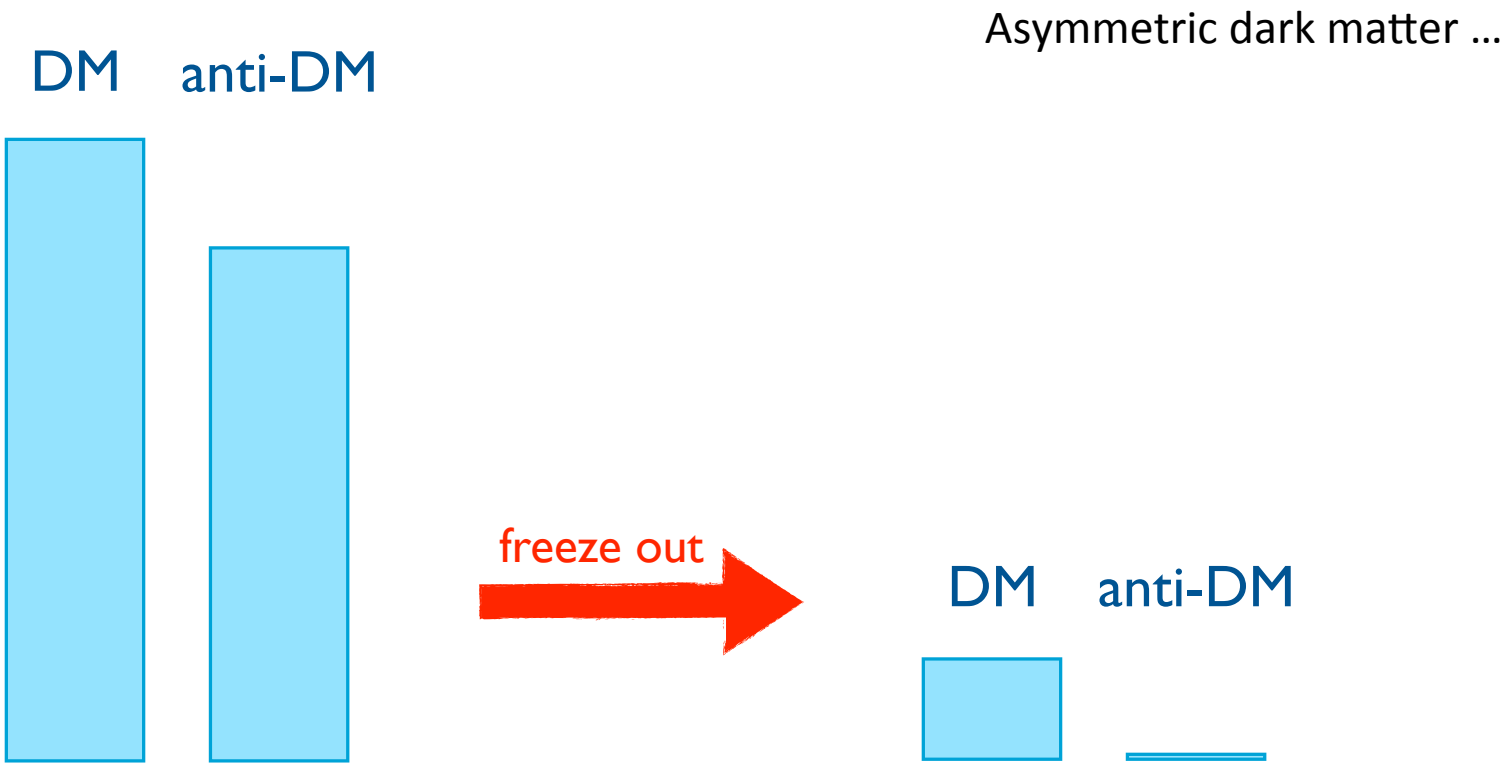
Good prospect for indirect detection
because of relatively large wino annihilation section



- Fermi gamma ray search already constrains the model
- AMS-02 antiproton search will probe significant parameter space

Cheung: Host of non-WIMP DM candidates

The symmetric component annihilates away when the dark matter freezes out.



Jiji Fan: A dissipative dark matter component

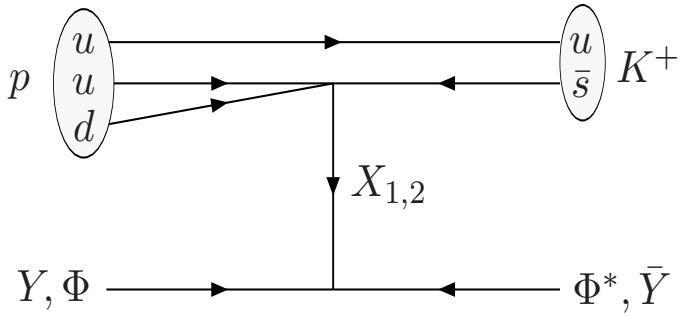
Is there a dark matter disk?

Sigurdson: Destruction of nucleon in dark-matter scatters

Induced Nucleon Decay

Detectable in Super-K?

- DM now carries $B = -1$!
- Y or Φ can scatter inelastically off a nucleon.

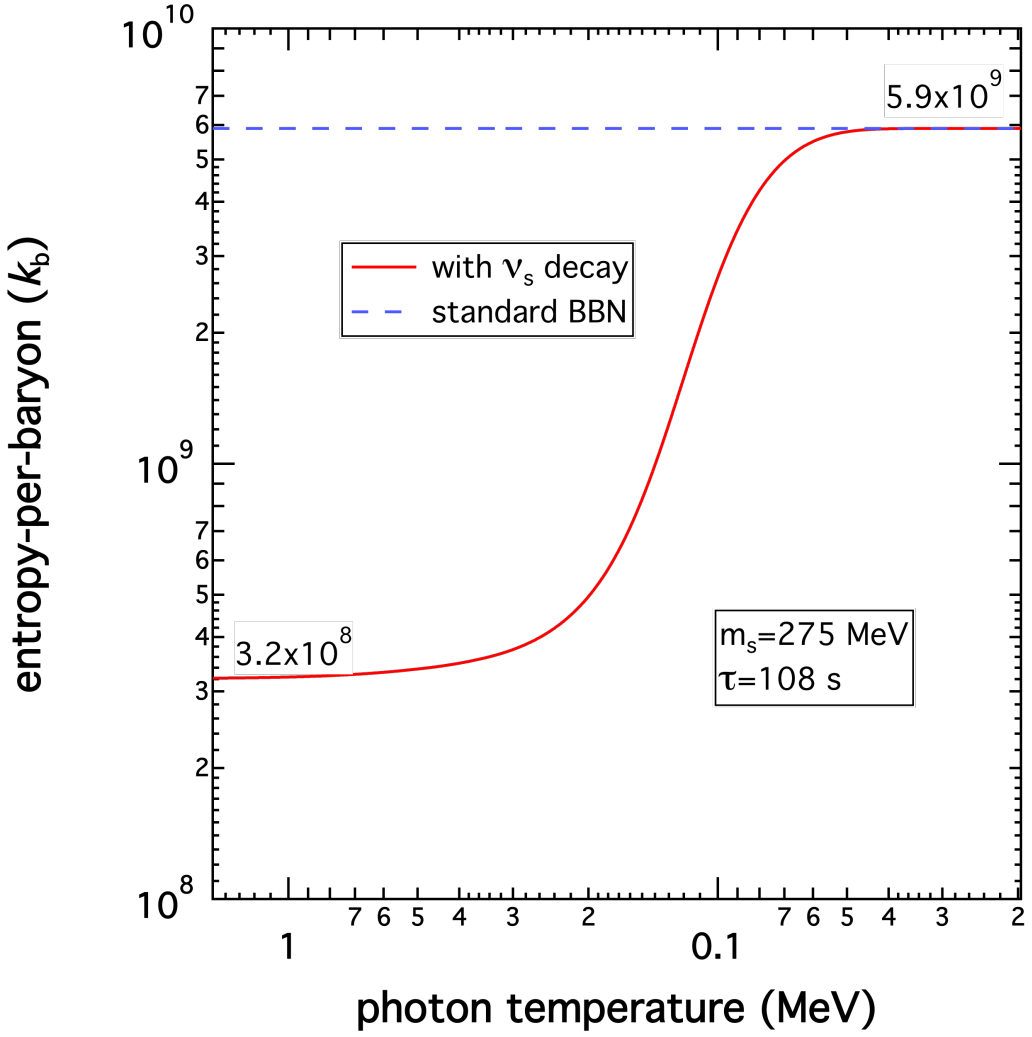


- A nucleon is destroyed in this process.

$$Y/\Phi + N \to \Phi^*/\bar{Y} + M$$

Fuller: Sterile neutrinos

Does a second sterile neutrino dilute the first?
Dark matter & dark radiation.



prodigious entropy production!

in this case:

$$F = \frac{s_{\rm final}}{s_{\rm initial}} \approx 18.4$$

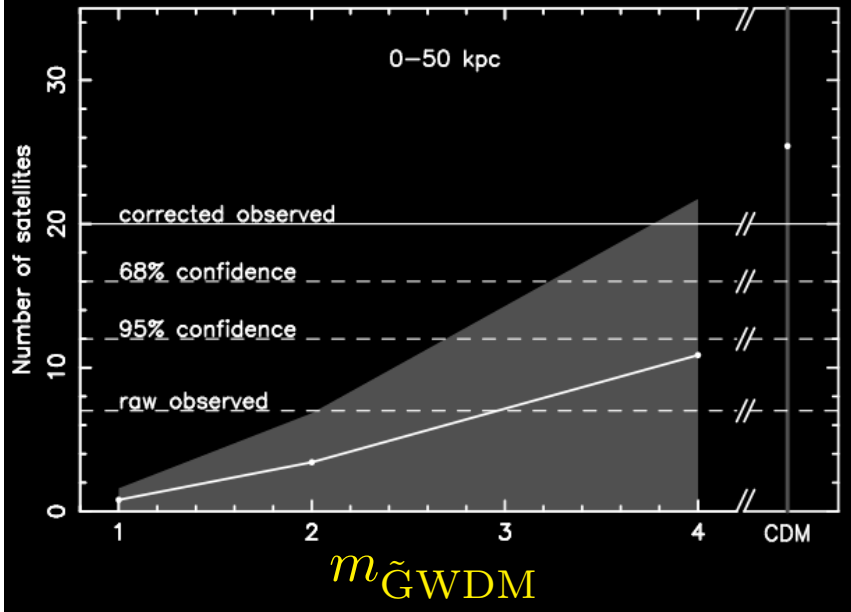
where entropy-per-baryon is carried by radiation

$$s = \frac{\left[\frac{2\pi^2}{45}\, g\, T^3\right]}{n_{\rm b}}$$

Abazajian: More sterile neutrinos

Sterile neutrinos, WDM and galaxies.

Turning an astrophysical signal into a constraint: The Dwarf galaxy count in the Milky Way



Coma Berenics	44 ± 4	4.6 ± 0.8	-3.7	[75, 78]
Bootes II	60 ± 10	-	-3.1	[79]
Bootes I	62 ± 3	$6.5^{+2.0}_{-1.4}$	-5.8	[74]
Pisces I	80 ± 14	-	-	[80, 81]
Ursa Major I	106^{+9}_{-8}	7.6 ± 1.0	-5.6	[75]
Hercules	140^{+13}_{-12}	5.1 ± 0.9	-6.0	[75, 78]
Canes Venatici II	150^{+15}_{-14}	4.6 ± 1.0	-4.8	[75, 78]
Leo IV	160^{+15}_{-14}	3.3 ± 1.7	-5.8	[75, 78]
Leo V	175 ± 9	2.4 ± 1.8	-5.2	[82, 83]

- Eventually, WDM is too much of a good thing, oversupression of the dwarf galaxy scale
- SDSS has found a large population of new dwarf galaxies in the MW local group

$m_{\tilde{\mathrm{G}}} \gtrsim 2 \text{ keV}$

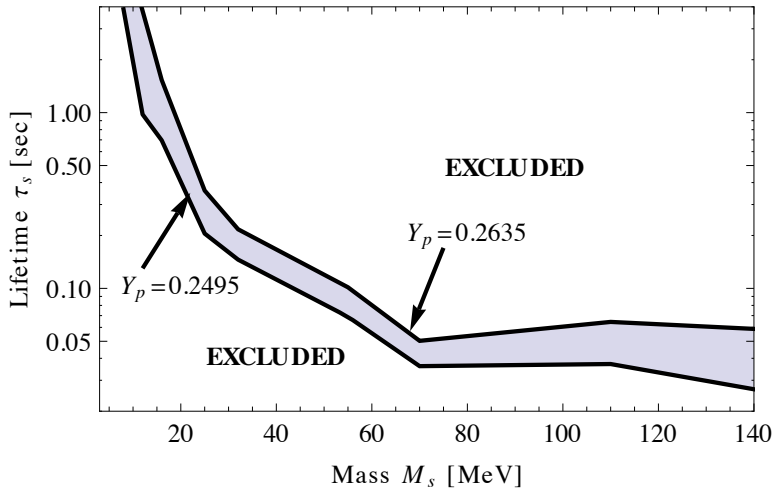
$m_s \gtrsim 10 \text{ keV}$

Polisensky & Ricotti (2011)

Ruchayskiy: Yet more sterile neutrinos

Sterile neutrinos and the early universe ...

Sterile neutrinos and the early Universe



Sterile neutrinos with the lifetime $\mathcal{O}(0.1)$ sec would affect primordial nucleosynthesis

Cline: DAMA/LIBRA & CoGeNT, what's going on?

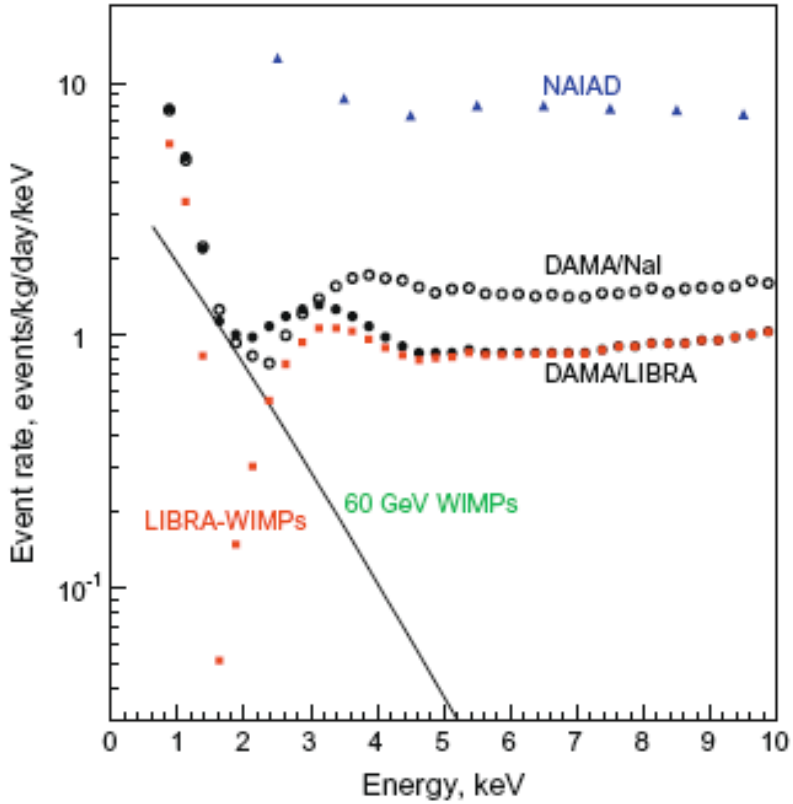
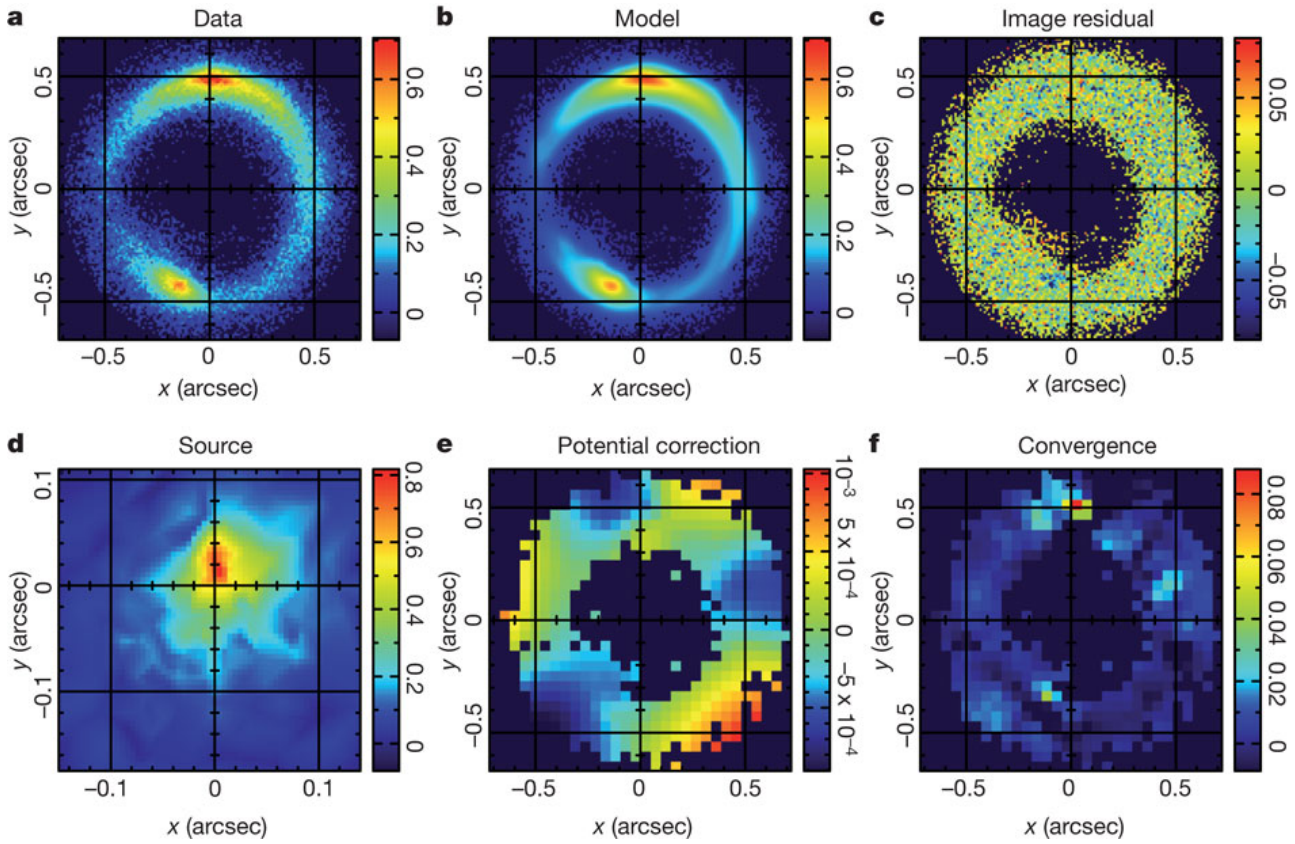


Fig. 3. Energy spectra of single hit events as reported by the DAMA/NaI [2] (open circles) and DAMA/LIBRA [3] (filled circles) experiments. The spectrum of events expected from 60 GeV WIMP interactions with the spin-independent cross-section of 7×10^{-6} pb in the isothermal halo model is shown as example by the solid curve (labeled as '60 GeV WIMPs'). The difference between the measured DAMA/LIBRA spectrum and the WIMP signal is plotted as filled squares (labeled as 'LIBRA-WIMPs'). An example spectrum from one of the NAIAD crystals is shown by filled triangles.

Does this make sense?

Moustakis: Strong Gravitational lenses and dark matter halos

B1938+666 (z=0.881; 7.2Gyr back)

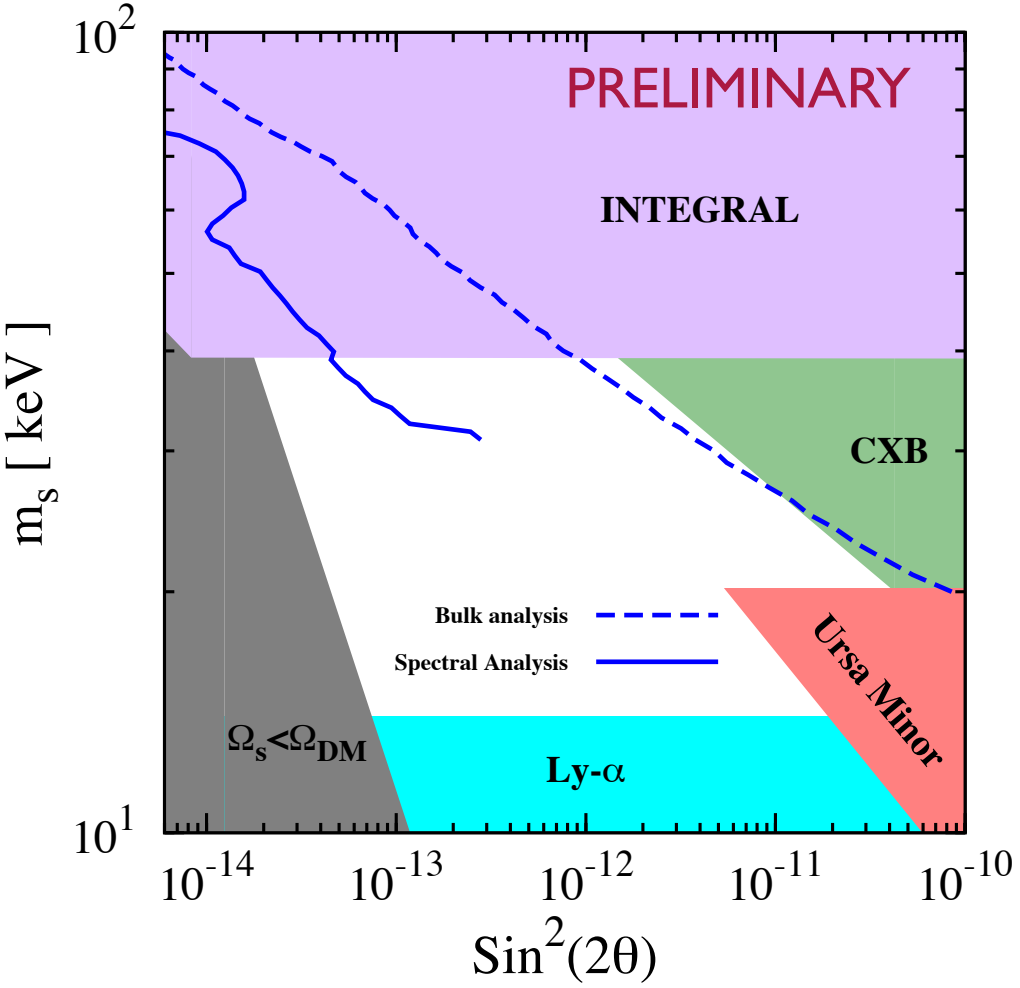


One can start to resolve halo structure

~2E8 solar masses

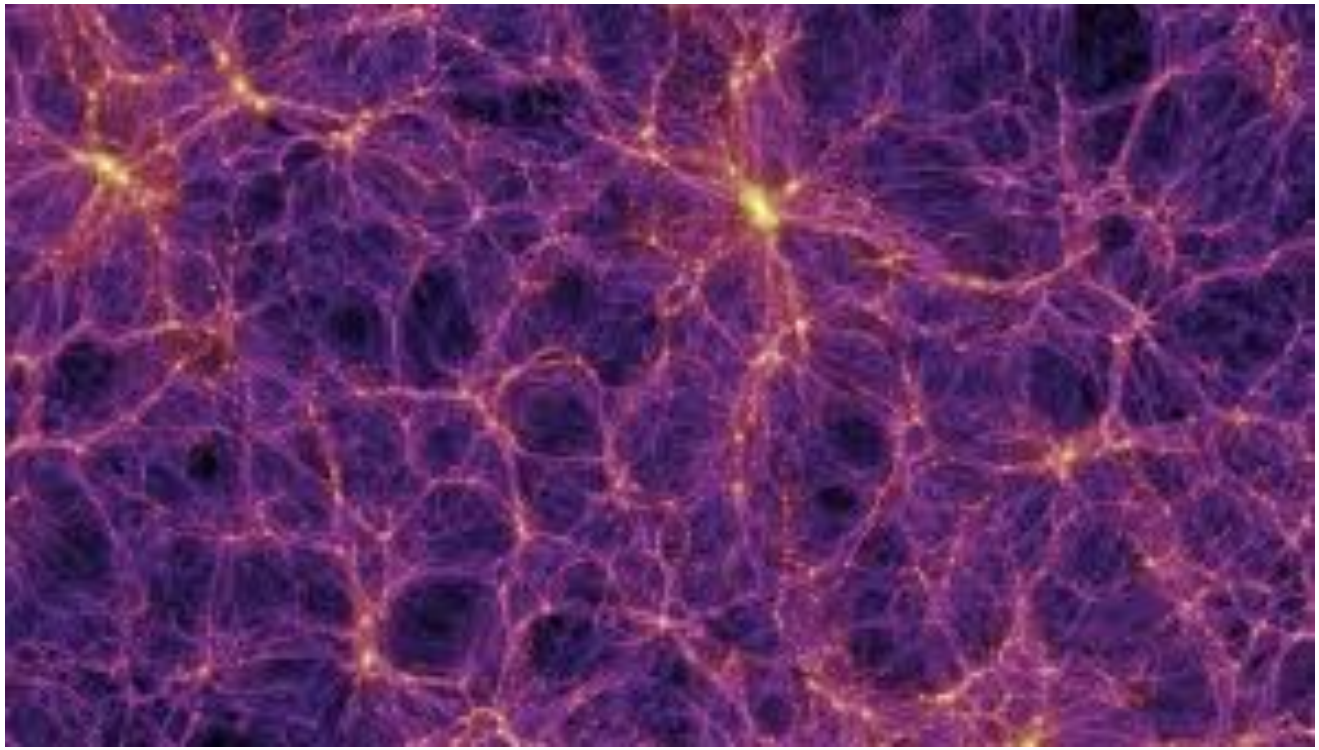
ɛtti+2012 Nature, 481, 341

Siegal-Gaskins: Sterile neutrinos and the Fermi GRB monitor



May provide powerful constraints

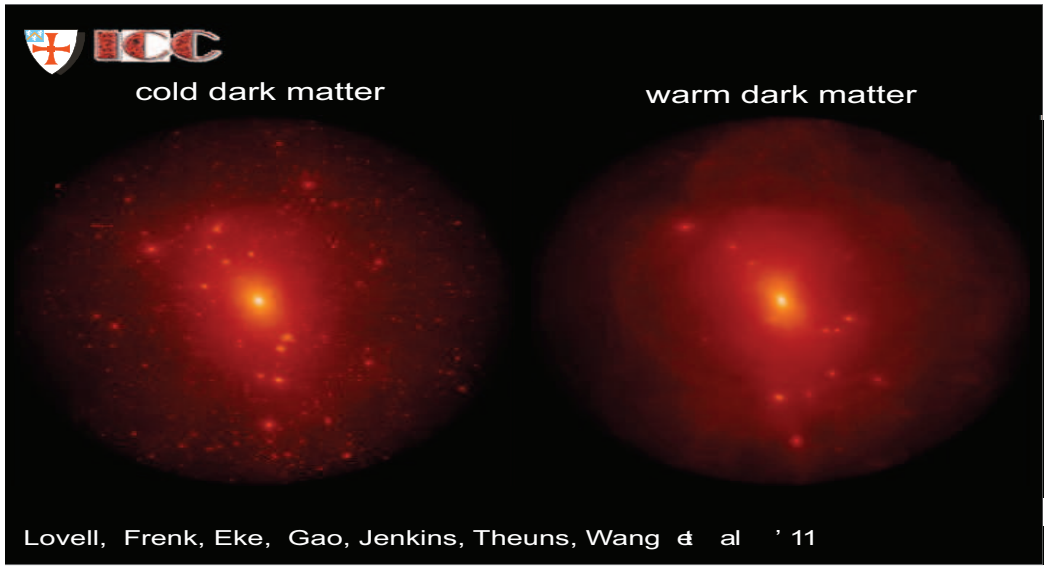
Stigari: What's up with small-scale structure?



Dwarf-spheroidal masses and counts.
WDM?
Self interactions?

de Vega: Quantum mechanics and WDM

N-body WDM Simulations: substructure formation



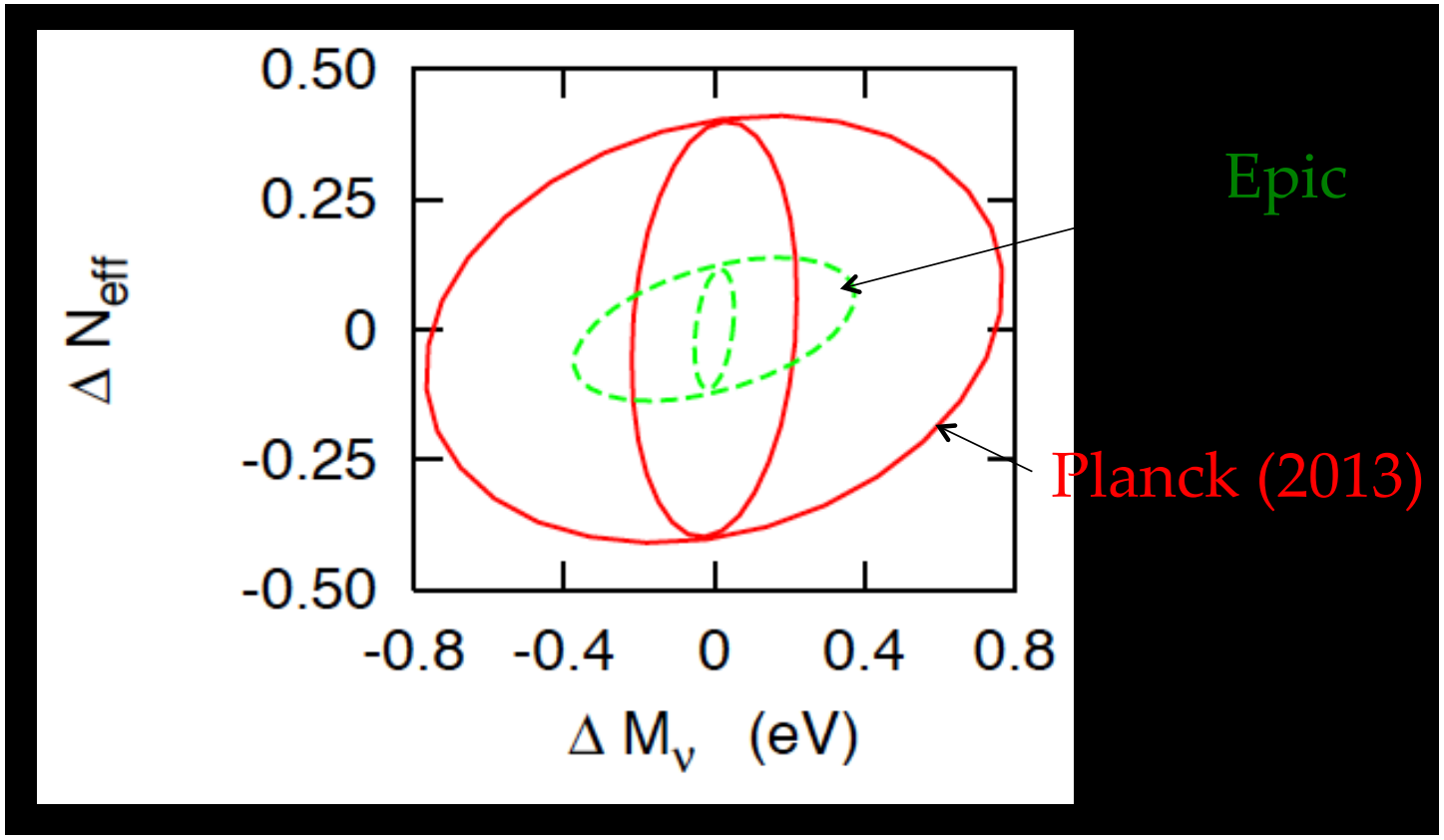
How compelling is WDM?

WDM subhalos are less concentrated than CDM subhalos.

WDM subhalos have the right concentration to host the bright Milky Way satellites. Lovell et al. MNRAS (2012).

Summary: WDM produces correct substructure abundance.

Dodelson: What neutrinos tell us



Example: Precision in the CMB

Next meeting:
SnowDark March 22-25
SnowBird, UT

www.physics.utah.edu/snowpac/index.php/snowdark-2013

You'll be hearing from us.
We need your input.
Make discoveries.